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# Air Pollution Meteorology During the Houston Urban Plume Study, July 1974

INTERA Environmental Consultants Ltd., Houston, Texas

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# AIR POLLUTION METEOROLOGY DURING THE HOUSTON URBAN PLUME STUDY, JULY 1974

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## ABSTRACT

Meteorological parameters were measured during an EPA sponsored air sampling program from 15-24 July, 1974, in Houston, Texas. The data collected are primarily surface anemometer data and pilot-balloon soundings to 1830 meters above ground. These measured data, along with piece from the National Weather Service, have been utilized to provide an overall meteorological analysis of conditions during the sampling program. Because the air sampling was performed primarily from a fixed-wind aircraft, emphasis was given to the ambient environment aloft.

This report was submitted in fulfillment of Contract No. 5-02-0025A by the INTERA Environmental Consultants, Ltd. under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from 1 July 1974 to 1 July 1975, and work was completed as of May 1977.

## ACKNOWLEDGEMENTS

The National Weather Service (NWS) Houston office, was of special assistance in both the data recovering and the forecasting efforts. The use of the Environmental Meteorological Support Unit (EMSU) site for pilot-balloon releases, and the helpfulness of the EMSU staff is also appreciated. Special thanks go to Mr. Ervin Vollbrecht, the Meteorologist-in-Charge of the Houston office, and Mr. William Cope, the EMSU Meteorologist.

The pilot-balloon soundings were taken by the United States Air Force, Air Weather Service, 6th Mobile Weather Squadron, Tinker AFB--with the assistance of students from Texas A&M University, University of Texas School of Public Health, and North Carolina State University.

The forecasting phase was also assisted by the Texas Air Control Board, Meteorology Section. Mr. Rollie Schrader was consulted prior to each forecast so that the most accurate forecast possible could be presented to the aircraft sampling team.

Mr. Tim Dujesdahy, meteorologist with the Environmental Protection Department, Houston Lighting and Power Company, collected data from a recently installed ambient air quality network.

The advice and assistance of Dr. James R. Brock of the Department of Chemical Engineering, University of Texas at Austin, is also appreciated.

Deep appreciation also goes to all the personnel who worked long hours out in the field at tedious jobs.

# SECTION 1

# INTRODUCTION

During July 1974, the Aerosol Research Branch, Atmospheric Chemistry and Physics Division, United States Environmental Protection Agency sponsored a field investigation,/"Houston Urban Plume Study."/ This report represents a limited portion of that study's results.

The meteorological support was to provide two services.

First, forecasts of weather conditions were made to facilitate planning for the sampling exercises. These forecasts included cloud cover, precipitation probability, general weather trends, and diffusion-related parameters such as inversion height and the average wind speed and direction in that inversion layer. The forecasting skill obtained during the study period is of little import to the analysis of the data and will not be discussed.

Second, the meteorological effort was directed towards data collection. NWS data was obtained from the Houston office. The U.S. Air Force sent a team of weather observation personnel from the 6th Mobile Weather Squadron to take pilot-balloon observations during sampling operations. Houston Lighting and Power provided available surface wind measurements from their ambient air quality network.

All of this information is included here so that the report may serve as a single reference to the meteorology of the sampling period.

## SECTION 8

## CONCLUSIONS AND RECOMMENDATIONS

1. The Houston Urban Plume Study represents an unusual meteorological situation. A strong, persistent high over Arkansas prevented normal weather systems from penetrating into the Houston area (the same high pressure center was responsible for the lengthy summer drought in the Great Plains).

2. This high allowed a mesoscale pattern of consistent, strong, low-level, westerly-to-southwesterly flow on each successive morning. Consequently, the inversion layer was well ventilated.

3. Because of opposing flow for low-level and upper-level winds, most of the mornings experienced a very calm transition zone between 910 and 1530 meters. Flows in this zone were very weak and variable in direction.

4. It would be useful to compare this period of relatively constant westerly surface flows with what is expected for a Houston summer. Southwest to westerly winds are the least frequent wind directions for Houston; and yet, here were six consecutive days with inversion winds from those directions.

5. Future studies should cover a longer period of time in order to increase the possibility of obtaining data for more unusual climatic circumstances.

## SECTION 3

## EXPERIMENTAL PROCEDURES

### PILOT BALLOONS

Pilot balloons were used to determine wind speed and wind direction above the ground. Wind speed and direction were calculated on a plotting board for elevations up to 1200 m (3600 ft.). Six locations were used each day. One position was switched from Conroe, Texas, (the day of 19 July, 1974, only), to the San Jacinto Monument Site and to Galveston (the day of 24 July, 1974 only). All of the pilot-balloon sites are shown in Figure 1 and ground-level anemometer sites. Pilot balloons were taken to the ENSU site in order to provide consistency with the rawinsonde data, and because the site is an excellent central urban site. At 0700 Central Daylight Time (CDT) each morning, the rawinsonde and a pibal were released simultaneously to assure consistency. This procedure was essential to reconstructing the pilot-balloon release program. The other sites were selected to provide data in all four quadrants from the central site and, in the case of the San Jacinto site, to be downwind of the central urban area. Tables 1-47 give the hour-by-hour pilot-balloon results at up to six sites. The rawinsonde data is included at 0700 CDT each day.

In order to retain clarity, only the data points at even 190 m (600-ft) intervals are reported. The nominal 190 m (600-ft) height has been approximated from an ascension rate of 185 m/min (606.8 ft/min). This was obtained with 30-g balloons filled to a nominal 139 g of free lift with helium.

The use of single, theodolite, pilot-balloon observations presupposes that the ascension rate is known and constant. Variations in actual free lift given to the balloon and vertical velocities in the atmosphere may alter the ascension rate from the nominal values. On hot, summer afternoons in August, the heating at ground surface creates convective activity which results in significant vertical velocities. Steep inversions can, through

temperature differences, retard the ascension of a balloon. Inaccurate filling can be easily spotted if the calculated wind speed is directly proportional to the ascension rate. For instance, at the Aldine site at 1000 CDT on 22 July (Table II), the wind speeds are much faster than the speeds measured simultaneously at the other sites--it is suspected the balloon was overfilled. However, problems with ascension rate are usually hard to detect.

SURFACE DATA

Measurements of meteorological parameters at the surface are recorded on Tables 48-53. These data include wind speeds and directions for the standard 10-m height from both NWS sites (ENRS/ and Intercontinental) and the Houston Lighting and Power ambient air quality monitoring network. The locations of these sites are marked on Figure 1. That network had just begun operational and although the data has some gaps, it does provide some interesting additions. Temperature, dew-point, and cloud cover descriptions are added for the Intercontinental location.

Meteorological Analysis

General--

Because this analysis has been accomplished without knowledge of the sampling results, it will not seek to explain those results. Consequently, the present analysis will not be biased by the experimentally observed concentrations of pollutants.

13-18 July, 1974--During this period, the sampling portion of the study was restricted. This was in part due to the set up of equipment, but primarily due to powerful thunderstorms from the Gulf of Mexico. Sampling data taken on the morning of the 16th is not included here because of the preliminary nature of sampling. By 18 July, none of the thunderstorms generated out in the Gulf made landfall. The morning rawinsonde on the 18th showed only a very shallow surface inversion (150 m). That inversion helped to trap water vapor brought in by southeasterly breezes at groundlevel, and brought the dew-point almost equal to the dry-bulb temperature. Above the inversion, the air was very dry. The wind directions at the rawinsonde stations in Victoria (Texas), Houston, and Lake Charles (Louisiana) indicated

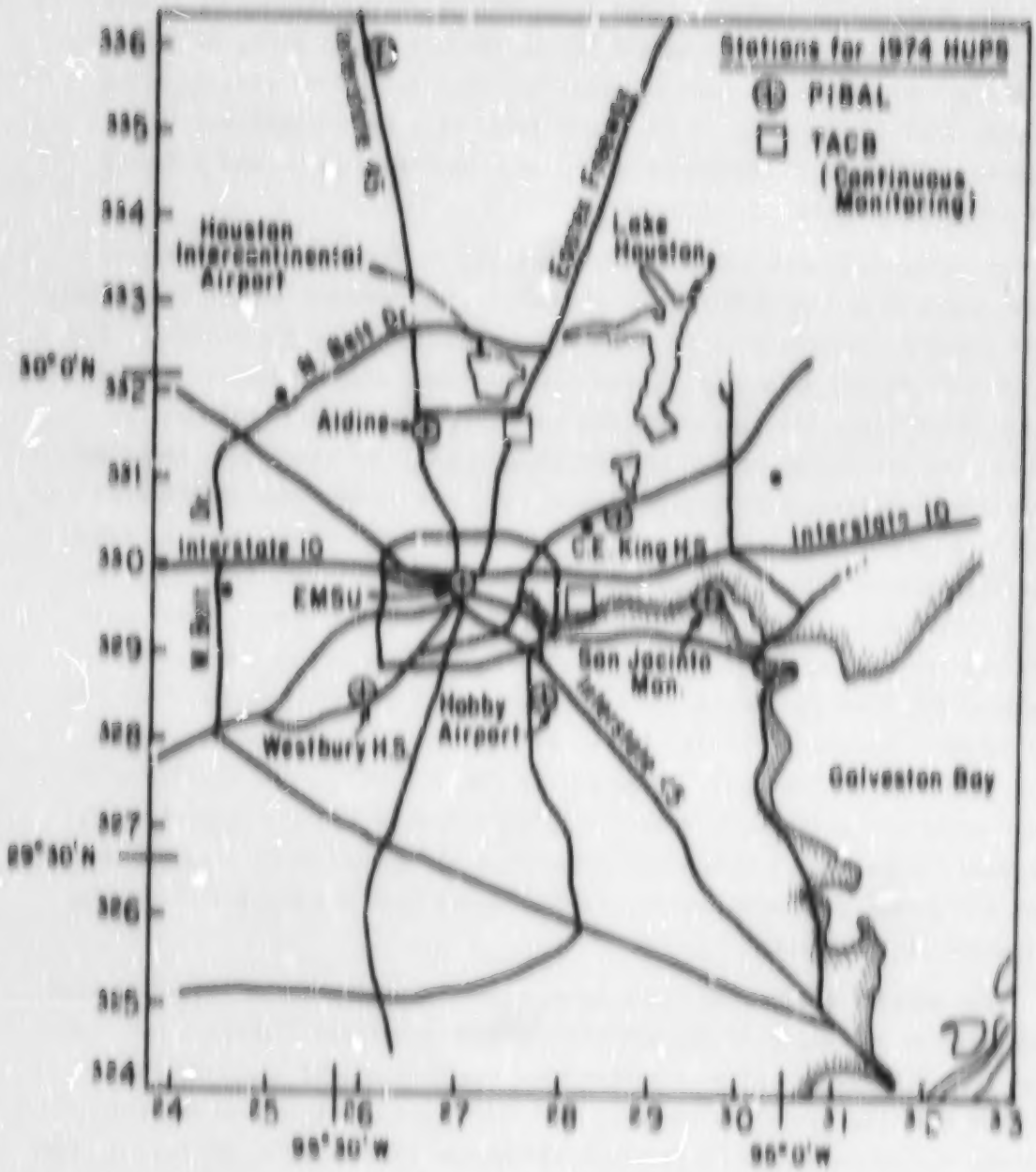



Figure 1. Site locations

that the flow was along the coast, i.e. Victoria from the SSW, Houston from the SW, and Lake Charles from the WSW. This was typical of the period during the sampling study.

The synoptic situation through the sampling period (Figure 2) showed only small surface pressure changes across the Gulf Coast area, and small day-to-day changes in the weather pattern. Frontal systems were crossing the U.S. well to the north of the study area, with the closest one in Oklahoma. There was a predominance of local weather control and a fairly uniform diurnal cycle was expected.

19 July, 1974--The sampling program began in earnest on 19 July. The 00 Greenwich Mean Time (GMT) (1900 CDT on 18 July) weather charts showed only small pressure changes across the entire southern half of the country. The 850 mb and the 700 mb charts had two high-pressure areas plotted: one in the middle south (Arkansas eastward), and the other, offshore in the Gulf of Mexico. At the center of and between these highs, the winds were light and conducive to inversion formation. On the surface chart, this entire area showed up as one large, continuous, high-pressure area since the wind flows were scattered in direction and weak. By morning (1200 GMT-0700 CDT), the highs at all three pressure levels had shifted around a little; but, again they were not very meaningful. The 1200 GMT rawinsonde showed that, in Houston, the inversion depth was much greater (6500 m) than it had been the day before. Again, the lowest layer had high water vapor content. Above this layer the air was very dry up to the 750 mb level. Lake Charles also experienced a significantly deeper inversion than it had the previous day. The wind in the lowest 1220 m reflected flow along the coast, suggesting that a high-pressure area was off the coast and that the dry air was coming primarily up the coast.

The general pattern of light winds from the southwest continued through 1000 CDT, as evidenced in the pilot-balloon observations (Tables 1-10). At that hour, the winds became a little more westerly at all the stations. By 1300 CDT, the winds had become almost calm throughout the urban area. Perhaps a certain amount of vertical mixing was taking place and the vertical windflows would be much more important than the recorded horizontal winds.

In the morning, the wind speeds closer to the ground were higher than they were at 910 m and above. It was supposed that the lowest layer was an independent system, and that the velocities were reduced above as the air patterns in the upper layers took over. Above 650 m (2100 ft), the inversion was no longer a factor, and the adiabatic layer was dominated by winds from a different direction.

Note that pibal observations tend to smooth the wind direction changes. The afternoon pibals do not show much consistency and probably reflect intense convective activity.

Throughout the rest of the day, the surface-weather maps showed high-pressure centers at various places on the map. These centers were responsive more to very slight shifts in pressure than to specific patterns.

20 July, 1974--By 00 GMT on 20 July (1900 CDT on the 19 July), a high-pressure area became well formed above Arkansas. This showed up on the 850 and 700 mb charts, but not at the surface. By 1200 GMT (0700 CDT), the surface map showed the highest pressure over Houston. The winds, as recorded by the rawinsonde and pibals at the same time, showed fairly strong flow at the surface from the west-southwest. At Victoria, the surface flow was more southerly; at Lake Charles it was west-northwest. This indicates that the actual high-pressure area probably was offshore because the winds were in and along the coast arc.

Above the surface layer, the winds were easterly and appeared to be directed by the upper-level high over Arkansas. The rawinsonde at 0700 CDT showed this best. Above 1500 m (5000 ft) the winds were all easterly. This easterly flow resulted in more water vapor above Houston than was available the day before when winds aloft were from the north. In the surface layer, the water vapor content was much higher. The inversion responsible for trapping the water vapor was 420 m thick and not very stable.

The winds in the two layers were, therefore, in almost opposite directions. This resulted in a null point (area of much reduced wind speed) at the boundary between the layers. The pilot balloons (Table 2) showed that this layer of dead air started at 910 m (3000 ft) and extended upward beyond the

pibal data. The low-level winds were especially fast, considering the synoptic situation. At 360 m (1200 ft) at 0700 CDT, the winds almost reached 30 kn. The differential temperature between land and the Gulf was probably responsible for this flow.

As one follows the pilot-balloon record hour-by-hour through the day, it can be seen that the low-level jet decreased in strength. At 910 m (3000 ft), however, the low-flow continued, thus indicating that the reversal of wind flows remained. By 1300 CDT (Table 17) the westerly-flow pattern had been modified. The source of the low-level jet had been reduced by the same heating of the earth's surface which had removed the inversion. By 1700 CDT (Table 21) the wind flows were light and variable at each station. The mixed layer was expected to be 1900 m thick (based on a maximum surface temperature of 94° recorded at Intercontinental Airport). Any pollutants from ground surface might then have been mixed through that entire height.

21 July, 1976--By the next morning (1200 GMT and 0700 CDT on 21 July) there was a low situated over Montana with long, sweeping surface fronts heading east toward Tennessee and west toward Colorado. These fronts were weak and slow moving. At the 850 mb and 700 mb heights, the upper-air high remained riveted to the northern Arkansas area. Although some data are missing, the rawinsonde again showed the easterly flow associated with that upper-air high. Again, the starting height was about 1500 m.

The winds in the surface layer were also the same as the previous day, i.e. westerly at appreciable speeds. At 0700 CDT the rawinsonde and the pibals (Table 24) recorded up to 16 kn at the 360 m (1200 ft) height. These flows followed the general curvature of the coastline. Most inland stations reported calm winds. (The San Jacinto pilot-balloon data appears to be incorrect for the day.) It is evident from the pibals that, above 910 m (3000 ft), the winds were almost calm in the transition zone between westerly flows at the surface and easterly flows above.

The temperature data from the rawinsonde showed a smaller (150 m), more stable, inversion than the day before. Because there was not as much water vapor in the lowest layers, it was supposed that the air was a little more continental in origin than was the case the previous day.

The pilot balloons up through 1000 CDT generally show a weakening of the westerly flow. The maximum temperature for the day was 97°F at 1500 CDT--the mixed layer probably exceeded 2000 m by that time.

22 July, 1974--By 1500 GMT (0700 CDT) on 22 July, the western surface from the low in Iowa had slipped into the Panhandle of Texas. The upper-air high over Arkansas was keeping the Houston area in clear weather and providing easterly flow aloft.

The rawinsondes showed the same picture as on previous days: fast, low-level flow along the coastline with easterly flow above. The temperature profile showed only a weak inversion through 500 m, but indicated a somewhat more continental air origin because of its relative dryness. By this time, the upper air had become fairly wet.

The pilot balloon data (Tables 28 to 37) showed the strength of the westerly flows at 0700 CDT. The flows at 910 m (3000 ft) appeared to be a little stronger than they had been the previous days, perhaps because the wind flow above was northeasterly and the turning was not so difficult. As the day progressed, the flow at that height picked up speed and became northerly. Evidently, the flow was dominated by the upper-level high which had moved down into north Texas. This resulted in a more northerly flow above Houston.

In response to the large amount of surface heating (96°F maximum), the windflow at the surface became light by the afternoon. Mixing probably occurred through a layer 1700 m thick.

23 July, 1974--The surface front had completely stagnated in north Texas by 0700 CDT on 23 July. Its influence on Houston windflow was expected to increase the westerly component. But, the surface flows as evidenced by the pibals (Table 38) were more southwesterly than they had been the previous two days. The upper-air high was not as intense as before and the result was only light easterly flow above Houston.

The rawinsonde data showed a ragged temperature inversion which might be listed as 205 at 500 m thick. The high water-vapor levels continued up to the 500 m height; so 500 m was selected as the inversion height. The

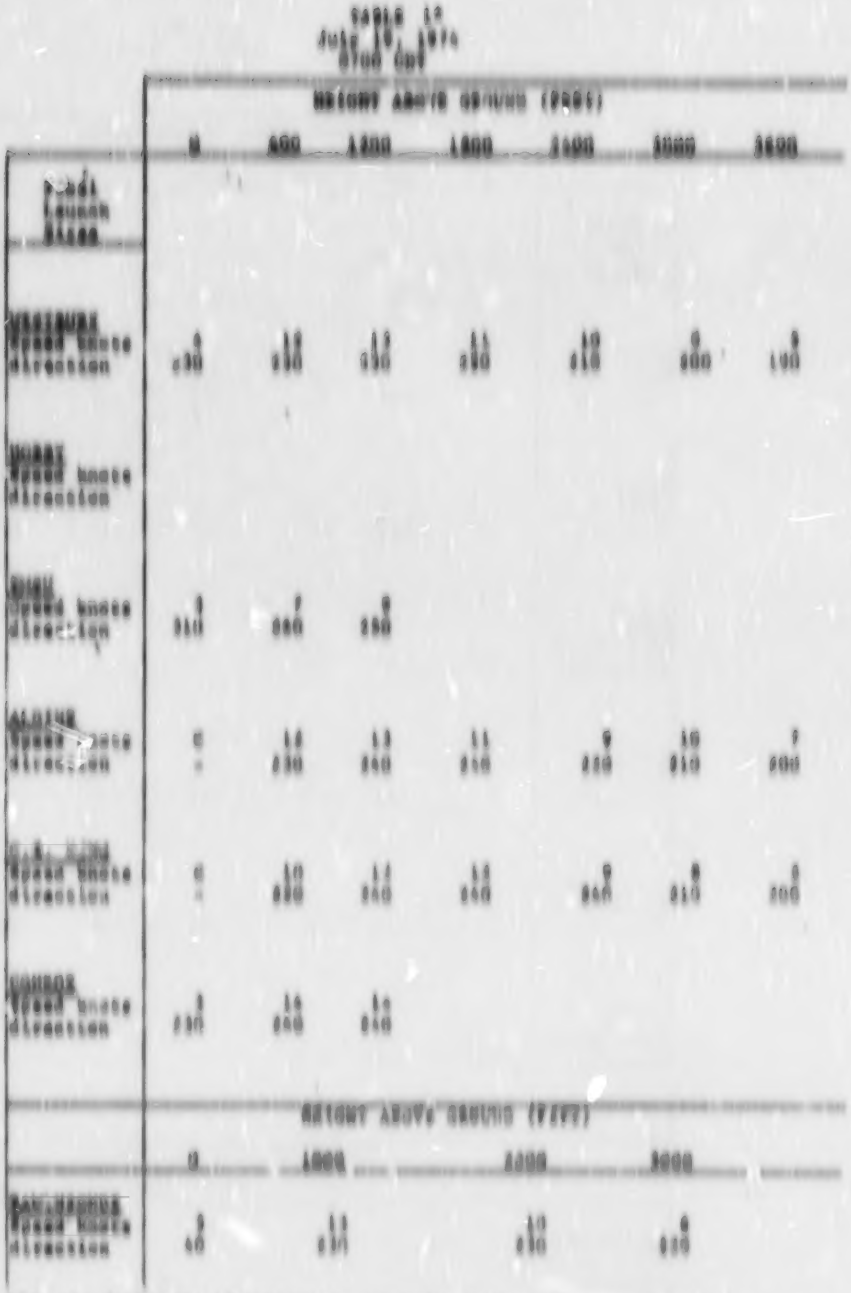
low-level flow probably had come off the Gulf since it was a little more moist than before.

The pilot-balloon data (Tables 38 to 42) again show strong flows which decreased gradually until they were 5 kn at 1800 CDT. The flows in the region between the low-level and upper-level patterns were light southerly, which was the first morning they backed (gone counterclockwise) with height rather than veered (gone clockwise).

24 July, 1976--By 0700 CDT (1300 GMT) on 24 July, the synoptic situation had changed sufficiently to increase the wind speed at all heights. The 700 mb chart showed that a high out in the Gulf had become linked to the same familiar high over north Texas. This led to fairly strong easterly flows. The rawinsonde recorded 36 kn at 2740 m (9000 ft) from the southeast. Meanwhile, the low-level winds had also accelerated to above 20 kn because of a offshore-high and an inland-low.

The winds again backed with height as observed in the rawinsonde data. The inversion probably only existed through 200 m because the air was only weakly stable above that height. Although the air aloft was quite dry, it still retained sufficient water vapor to indicate a Gulf origin.

The high winds continued through the day until 1167 CDT, at which time they started to drop off in the lowest levels. Another day of good ground surface heating resulted in lower flows close to the ground; but aloft, the upper-air pattern persisted.



After the following 17 tables see Appendix A for conversion factors into SI

TABLE 2

July 19, 1974

[redacted]

| | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Pitot Launch Stand | | | | | | | |
| [redacted] Speed knots direction | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] Speed knots direction | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] Speed knots direction | [redacted] | [redacted] | [redacted] | | | | |
| [redacted] Speed knots direction | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] Speed knots direction | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] Speed knots direction | [redacted] | [redacted] | [redacted] | | | | |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | [redacted] | [redacted] | [redacted] |
| [redacted] Speed knots direction | | | | |

TABLE 4
July 19, 1974
[illegible]

| | WINDS ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 |
| Pibal Launch Data | | | | | | | |
| [illegible] Speed knots direction | 000 0 | 000 0 | 000 2 | 000 0 | 000 0 | 200 0 | 100 0 |
| [illegible] Speed knots direction | 000 0 | 000 0 | 000 0 | 010 | 000 1 | 000 1 | |
| [illegible] Speed knots direction | 000 0 | 000 0 | 000 0 | | | | |
| [illegible] Speed knots direction | 010 1 | 000 0 | 000 0 | 000 0 | 010 | 010 0 | 000 0 |
| [illegible] Speed knots direction | 000 0 | 000 0 | 000 0 | 000 0 | 000 1 | 000 0 | 100 1 |
| [illegible] Speed knots direction | 000 1 | 010 1 | 000 0 | | | | |

| | WINDS ALOFT ABOVE INDIAN (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Speed knots direction | | | | |

TABLE 3

WIND SHEAR DATA

| Final Launch Azimuth | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 |
| [illegible] | [illegible] | | | | | | |
| [illegible] | [illegible] | | | | | | |
| [illegible] | [illegible] | | | | | |

TABLE 6
July 19, 1974

| Final launch plane | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE 9
July 18, 1974

| | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 600 | 1800 | 1000 | 2400 | 000 | 3000 |
| Final Launch Sites | | | | | | | |
| WHITEHURST Speed knots direction | | | | | | | |
| HORSE Speed knots direction | | | | | | | |
| KNOX Speed knots direction | 0 180 | 0 180 | 0 10 | | | | |
| ALDRIN Speed knots direction | 0 - | 0 280 | 0 100 | 0 100 | 0 210 | 0 300 | 0 120 |
| U.S. KING Speed knots direction | | | | | | | |
| COLLINS Speed knots direction | 0 180 | 0 180 | 0 170 | | | | |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| RAMSTRONG Speed knots direction | | | | |

TABLE 10
July 19, 1974
1601 GMT

| | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 600 | 1200 | 1800 | 2400 | 3000 | 3600 |
| Pilot Launch Azimuth | | | | | | | |
| WEATHER Speed knots direction | | | | | | | |
| NOAA Speed knots direction | | | | | | | |
| NOAA Speed knots direction | | | | | | | |
| ALOFT Speed knots direction | 0 0 | 0 0 | 0 31/ | 0 P10 | 0 010 | 0 050 | 0 050 |
| U.S. Navy Speed knots direction | | | | | | | |
| CORNELL Speed knots direction | 0 160 | 0 140 | 0 030 | | | | |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| RAWINSONDE Speed knots direction | | | | |

TABLE 11
July 29, 1974
0700 CDT

| Pibal Launch Sites | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 600 | 1200 | 1800 | 2400 | 3000 | 3600 |
| VANDENBERG<br>Speed knots<br>direction | 7<br>280 | 14<br>260 | 17<br>250 | 19<br>240 | 8<br>230 | 2<br>140 | 3<br>95 |
| HURST<br>Speed knots<br>direction | 2<br>280 | 15<br>280 | 16<br>260 | 13<br>260 | 3<br>230 | 2<br>140 | 3<br>90 |
| ADAK<br>Speed knots<br>direction | 9<br>240 | 13<br>260 | 19<br>260 | 19<br>260 | 12<br>240 | 4<br>240 | 3<br>260 |
| ALOTAU<br>Speed knots<br>direction | C<br>0 | C<br>0 | 10<br>260 | 16<br>240 | 8<br>230 | 5<br>240 | 3<br>210 |
| G.B. KING<br>Speed knots<br>direction | 6<br>0 | 15<br>260 | 17<br>260 | 10<br>250 | 8<br>250 | 3<br>260 | 3<br>210 |
| KWAJALEIN<br>Speed knots<br>direction | | | | | | | |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| ASCENSION<br>Speed knots<br>direction | 8<br>280 | 19<br>260 | 7<br>230 | 3<br>240 |

[illegible]

| Pibal Launch Sites | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 800 | 1200 | 1500 | 2400 | 3000 | 3600 |
| [illegible] Speed knots direction | 1 080 | 14 080 | 17 090 | 11 090 | 8 060 | 8 150 | 8 60 |
| [illegible] Speed knots direction | 4 080 | 13 080 | 10 080 | 10 080 | 9 061 | 8 090 | 8 80 |
| [illegible] Speed knots direction | 8 070 | 14 080 | 17 070 | 12 080 | 8 080 | 4 080 | 1 090 |
| [illegible] Speed knots direction | 4 070 | 10 080 | 10 080 | 14 080 | 9 080 | 8 080 | 8 060 |
| [illegible] Speed knots direction | 1 080 | 11 080 | 10 080 | 11 080 | 8 080 | 8 080 | 8 080 |
| [illegible] Speed knots direction | 10 080 | 13 080 | 11 070 | 10 070 | 6 060 | 8 080 | 6 60 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Speed knots direction | | | | |

TABLE II

July 30, 1974

0900 EDT

| Tidal Launch Areas | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 600 | 1200 | 1800 | 2400 | 3000 | 3600 |
| [illegible] Speed knots direction | 0 070 | 10 110 | 10 080 | 10 080 | 4 090 | 0 140 | 0 110 |
| [illegible] Speed knots direction | 0 040 | 14 070 | 14 070 | 10 080 | 0 080 | 0 170 | 0 60 |
| [illegible] Speed knots direction | 0 080 | 10 080 | 10 070 | 10 080 | 10 080 | 0 070 | 0 070 |
| [illegible] Speed knots direction | 0 080 | 0 070 | 10 080 | 10 070 | 0 080 | 0 070 | 1 070 |
| [illegible] Speed knots direction | 0 050 | 1 090 | 10 070 | 0 070 | 0 080 | 1 080 | 0 140 |
| [illegible] Speed knots direction | 10 080 | 10 080 | 10 080 | 0 090 | 0 080 | 0 080 | 1 40 |

| Tidal Launch Areas | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Speed knots direction | | | | |

TABLE 14
July 23, 1974
1000 GMT

| Tribal Launch Areas | HEIGHT ABOVE GROUND (FEET) 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 |
|---|---|---|---|---|---|---|---|
| WHITEWOOD Speed knots direction | 4 090 | 8 090 | 8 090 | 8 090 | 9 090 | 8 090 | 6 - |
| MURRAY Speed knots direction | 8 040 | 11 060 | 13 070 | 11 070 | 9 080 | 9 070 | 8 040 |
| BUSH Speed knots direction | 8 090 | 8 070 | 10 060 | 8 060 | 8 050 | 9 030 | |
| ALBINY Speed knots direction | 10 060 | 10 050 | 9 060 | 7 060 | 8 030 | 8 010 | 8 010 |
| [illegible] Speed knots direction | 8 030 | 13 060 | 14 060 | 11 060 | 9 070 | 9 060 | 8 110 |
| LOWDOG Speed knots direction | 8 000 | 8 000 | / 000 | 8 000 | 8 000 | 8 030 | 8 00 |

| | HEIGHT ABOVE GROUND (FEET) 0 | 1000 | 2000 | 3000 |
|---|---|---|---|---|
| RAPIDCREEK Speed knots direction | | | | |

TABLE II
July 30, 1974
AFB 0011

| Final Launch Azimuth | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 100 | 1000 | 2000 | 3000 | 4000 | 5000 |
| [illegible] Wind speed knots direction | 8 080 | 8 080 | 8 080 | 7 080 | 6 080 | 5 080 | 6 010 |
| [illegible] Wind speed knots direction | 8 080 | 7 080 | 6 080 | 6 080 | 8 010 | 8 010 | 11 080 |
| [illegible] Wind speed knots direction | 6 080 | 6 080 | 6 080 | 6 010 | 6 010 | 6 010 | 6 010 |
| [illegible] Wind speed knots direction | 6 080 | 7 080 | 7 070 | 6 070 | 6 080 | 6 070 | 6 080 |
| [illegible] Wind speed knots direction | 6 080 | 6 080 | 7 080 | 6 080 | 6 080 | 6 080 | 6 070 |
| [illegible] Wind speed knots direction | 6 080 | 5 080 | 11 080 | 6 080 | 6 080 | 5 080 | 5 080 |

| Final Launch Azimuth | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Wind speed knots direction | | | | |

TABLE 18
July 30, 1974
1100 EDT

| Tidal Launch Winds | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1800 | 3400 | 5000 | 7000 |
| KENNEDY Speed knots direction | 4<br>360 | 9<br>360 | 9<br>000 | 9<br>010 | 8<br>010 | 8<br>010 | 8<br>010 |
| MERRITT Speed knots direction | 3<br>340 | 8<br>360 | 7<br>000 | 7<br>000 | 8<br>000 | 8<br>010 | 8<br>040 |
| BANU Speed knots direction | 3<br>000 | 8<br>000 | 7<br>000 | 8<br>010 | 8<br>000 | 8<br>000 | 8<br>000 |
| CANAVERAL Speed knots direction | 4<br>000 | 8<br>000 | 8<br>000 | 8<br>000 | 8<br>010 | 8<br>010 | 8<br>010 |
| U.S. AIR Speed knots direction | 8<br>010 | 8<br>010 | 7<br>000 | 7<br>010 | 8<br>000 | 8<br>010 | 8<br>010 |
| SUNRISE Speed knots direction | 4<br>000 | 7<br>000 | 8<br>000 | 8<br>000 | 7<br>000 | 8<br>010 | 8<br>000 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 3000 | 5000 |
| SANFORD Speed knots direction | | | | |

TABLE 17
July 28, 1974
1100 CDT

| Pibal Launch Site | Height Above Ground (Feet) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 |
| Amarillo | | | | | | | |
| Speed knots | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| direction | 080 | 070 | 070 | 080 | 070 | 080 | 00 |
| Dodge | | | | | | | |
| Speed knots | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| direction | 080 | 080 | 090 | 100 | 090 | 090 | 00 |
| Ely | | | | | | | |
| Speed knots | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| direction | 000 | 000 | 000 | 010 | 00 | 000 | 010 |
| Glasgow | | | | | | | |
| Speed knots | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| direction | 000 | 000 | 070 | 070 | 000 | 000 | 060 |
| [illegible] | | | | | | | |
| Speed knots | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| direction | 080 | 080 | 090 | 080 | 070 | 080 | 070 |
| Lincoln | | | | | | | |
| Speed knots | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| direction | 080 | 080 | 070 | 080 | 080 | 080 | 060 |

| Pibal Launch Site | Height Above Ground (Feet) | | | | |
|---|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 | 4000 |
| Rawlins | | | | | |
| Speed knots | | | | | |
| direction | | | | | |

TABLE 10
July 30, 1974
ADO CDV

| Pibal Launch Sites | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 |
| [illegible] Speed knots direction | 5 010 | 8 000 | 7 060 | 8 060 | 8 060 | 7 110 | 7 160 |
| [illegible] Speed knots direction | 3 080 | 6 030 | 6 030 | 6 060 | 6 090 | 6 010 | 7 100 |
| [illegible] Speed knots direction | C | C | 3 00 | 4 000 | | | |
| [illegible] Speed knots direction | C | 3 010 | 3 100 | 3 00 | 3 100 | 3 110 | 3 110 |
| [illegible] Speed knots direction | C | 3 040 | 3 110 | 3 110 | 3 100 | 3 000 | 3 100 |
| [illegible] Speed knots direction | 3 100 | 3 10 | 3 060 | 3 110 | 3 110 | 3 110 | 3 000 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Speed knots direction | | | | |

[illegible]

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | | | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|
| [illegible] | [illegible] | | | |

TABLE II
July 30, 1974
1700 GMT

| Pikal Launch Sites | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1100 | 1800 | 2600 | 3500 | 4500 |
| [illegible] Speed knots direction | 3 270 | 2 280 | 0 310 | 0 330 | 0 340 | 0 340 | 0 350 |
| [illegible] Speed knots direction | 0 330 | 0 320 | 0 330 | 0 340 | 0 340 | 0 330 | 0 340 |
| [illegible] Speed knots direction | 1 330 | 0 180 | 0 180 | 0 180 | 0 190 | 0 - | 0 - |
| [illegible] Speed knots direction | 0 - | 0 - | 1 310 | 1 300 | 1 320 | 0 340 | 0 320 |
| [illegible] Speed knots direction | 0 160 | 0 150 | 0 200 | 1 170 | 1 170 | 1 210 | 0 240 |
| [illegible] Speed knots direction | 1 060 | 1 10 | 1 30 | 2 310 | 0 340 | 0 0 | 0 300 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1070 | 2450 | 3960 |
| [illegible] Speed knots direction | | | | |

TABLE II
July 20, 1974
GMT

| Pilot launch time | WINDS ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 3000 | 4000 |
| WEATHERLY Speed knots direction | 1<br>010 | 13<br>040 | 19<br>050 | 7<br>040 | 0<br>000 | 1<br>001 | 1<br>001 |
| HUGHES Speed knots direction | 0<br>000 | 11<br>040 | 7<br>040 | 0<br>001 | 0<br>040 | 0<br>001 | 1<br>03 |
| MSFC Speed knots direction | 0<br>000 | 11<br>040 | 19<br>050 | 10<br>050 | 0<br>000 | 0<br>040 | 0<br>050 |
| ALOFT Speed knots direction | | | | | | | |
| U.S. NAVY Speed knots direction | 0<br>010 | 13<br>050 | 19<br>060 | 11<br>060 | 0<br>050 | 0<br>050 | 0<br>070 |
| CLIMAX Speed knots direction | | | | | | | |

| Pilot launch time | WINDS ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| RAYTHEON Speed knots direction | | | | |

TABLE 17
July 31, 1974

| Pilot Launch Areas | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 |
| VANDENBERG Speed knots direction | 0 010 | 12 010 | 10 010 | 9 010 | 9 090 | 9 110 | 9 110 |
| KWAJ Speed knots direction | 0 040 | 10 070 | 11 070 | 9 070 | 9 090 | 9 110 | 9 110 |
| ATLIX Speed knots direction | 0 000 | 10 070 | 10 080 | 10 070 | 9 070 | 9 080 | 9 080 |
| ATLIX Speed knots direction | | | | | | | |
| C.C.A.F.S. Speed knots direction | 4 070 | 10 090 | 11 080 | 10 070 | 9 080 | 9 090 | 9 090 |
| EDWARDS Speed knots direction | 7 090 | 9 100 | 10 090 | 10 080 | 10 080 | 9 090 | 9 090 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| BARKSDALE Speed knots direction | | | | |

TABLE 10
July 23, 1974
0700 CDT

| Pibal Launch Sites | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 600 | 1200 | 1800 | 2400 | 3000 | 3600 |
| [illegible] | | | | | | | |
| Speed knots | 1 | 14 | 17 | 11 | 7 | 0 | 0 |
| direction | 000 | 010 | 040 | 010 | 000 | 000 | 000 |
| [illegible] | | | | | | | |
| Speed knots | 3 | 10 | 17 | 12 | 9 | 7 | 7 |
| direction | 050 | 050 | 040 | 040 | 070 | 090 | 110 |
| [illegible] | | | | | | | |
| Speed knots | 0 | 13 | 13 | 13 | 9 | 5 | 0 |
| direction | 000 | 010 | 060 | 060 | 000 | 010 | 000 |
| [illegible] | | | | | | | |
| Speed knots | 0 | 13 | 13 | 13 | 10 | 0 | 7 |
| direction | 060 | 060 | 060 | 060 | 070 | 000 | 070 |
| [illegible] | | | | | | | |
| Speed knots | 1 | 13 | 10 | 11 | 7 | 0 | 6 |
| direction | 000 | 000 | 060 | 060 | 070 | 090 | 110 |
| [illegible] | | | | | | | |
| Speed knots | 12 | 13 | 13 | 13 | 12 | 10 | 7 |
| direction | 060 | 060 | 060 | 070 | 060 | 090 | 000 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] | | | | |
| Speed knots | 0 | 13 | 11 | 10 |
| direction | 010 | 010 | 007 | 000 |

TABLE IV
July 23, 1976
0900 CDT

| Pibal Launch Sites | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 3000 | 4000 |
| [illegible] Speed knots direction | 3<br>010 | 15<br>010 | 16<br>060 | 13<br>050 | 8<br>010 | 9<br>040 | 9<br>030 |
| [illegible] Speed knots direction | 3<br>060 | 15<br>060 | 16<br>060 | 10<br>080 | 7<br>080 | 7<br>080 | 9<br>090 |
| [illegible] Speed knots direction | 9<br>090 | 13<br>100 | 16<br>060 | 15<br>060 | 10<br>070 | 9<br>060 | 9<br>060 |
| [illegible] Speed knots direction | C<br>- | 14<br>060 | 13<br>060 | 7<br>045 | 7<br>070 | 9<br>060 | 9<br>050 |
| [illegible] Speed knots direction | 6<br>010 | 13<br>060 | 17<br>070 | 13<br>070 | 8<br>060 | 9<br>60 | 14<br>07 |
| [illegible] Speed knots direction | 11<br>090 | 14<br>060 | 15<br>060 | 12<br>060 | 8<br>090 | 7<br>050 | 9<br>040 |

| | HEIGHT ABOVE [illegible] (FEET) | | | | |
|---|---|---|---|---|---|
| | 0 | [illegible] | [illegible] | [illegible] | |
| [illegible] Speed knots direction | | | | | |

TABLE II
July 23, 1974

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| | WIND ABOVE GROUND (MPH) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 250 | 500 | 1000 | 2000 | 3000 | 4000 |
| PIKE Launch Sites | | | | | | | |
| [illegible] Speed Knots Direction | 0 000 | 0 000 | 0 000 | 0 000 | 0 000 | 1 05 | 0 00 |
| [illegible] Speed Knots Direction | 0 000 | 1 000 | 0 000 | 0 000 | 0 000 | 0 00 | |
| [illegible] Speed Knots Direction | 0 0 | 0 0 | 0 000 | 0 000 | 0 000 | 0 00 | 0 00 |
| [illegible] Speed Knots Direction | 0 0 | 0 0 | 0 000 | 0 00 | 0 000 | 1 000 | 0 000 |
| [illegible] Speed Knots Direction | 1 010 | 1 000 | 0 000 | 1 10 | 0 00 | 10 00 | 10 00 |
| [illegible] Speed Knots Direction | 0 000 | 0 000 | 0 000 | 0 000 | | | |

| | WIND ABOVE GROUND (MPH) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Speed Knots Direction | | | | |

[redacted]

| Pilot Launch Areas | Height above ground (feet) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 3000 | 4500 |
| [illegible] Speed knots direction | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] Speed knots direction | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] Speed knots direction | | | | | | | |
| [illegible] Speed knots direction | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] Speed knots direction | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] Speed knots direction | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Height above ground (feet) | | | | | | |
| | 0 | [illegible] | [illegible] | [illegible] | [illegible] | | |
| [illegible] Speed knots direction | | | | | | | |

TABLE 10
July 21, 1976
STOP CUP

| | HEIGHT ABOVE GROUND (FEET) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 |
| Final Launch Azimuth | | | | | | | |
| [illegible] Wind Speed (knots) | 0 | 12 | 11 | 10 | 9 | 9 | 8 |
| Wind Direction | 040 | 030 | 040 | 030 | 010 | 010 | 010 |
| Wind Speed (knots) | 0 | 11 | 10 | 10 | 10 | 10 | 8 |
| Direction | 040 | 030 | 030 | 040 | 030 | 010 | 010 |
| Wind Speed (knots) | 0 | 11 | 10 | 10 | 11 | 9 | 9 |
| Direction | 040 | 040 | 030 | 040 | 030 | 030 | 010 |
| Wind Speed (knots) | 0 | 12 | 10 | 11 | 9 | 9 | 9 |
| Direction | 040 | 030 | 030 | 040 | 040 | 030 | 030 |
| Wind Speed (knots) | 1 | 10 | 9 | 9 | 9 | 9 | 9 |
| Direction | 040 | 040 | 030 | 040 | 030 | 010 | 010 |
| Wind Speed (knots) | 0 | 11 | 11 | 10 | 9 | 9 | 9 |
| Direction | 040 | 040 | 040 | 040 | 040 | 030 | 010 |

| | HEIGHT ABOVE GROUND (FEET) | | | |
|---|---|---|---|---|
| | 0 | 1000 | 2000 | 3000 |
| [illegible] Wind Speed (knots) | 0 | 10 | 11 | 9 |
| Direction | 040 | 040 | 040 | 010 |

[redacted]

[redacted]

| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
|---|---|---|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
|---|---|---|---|---|
| [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

TABLE 11

[illegible]

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

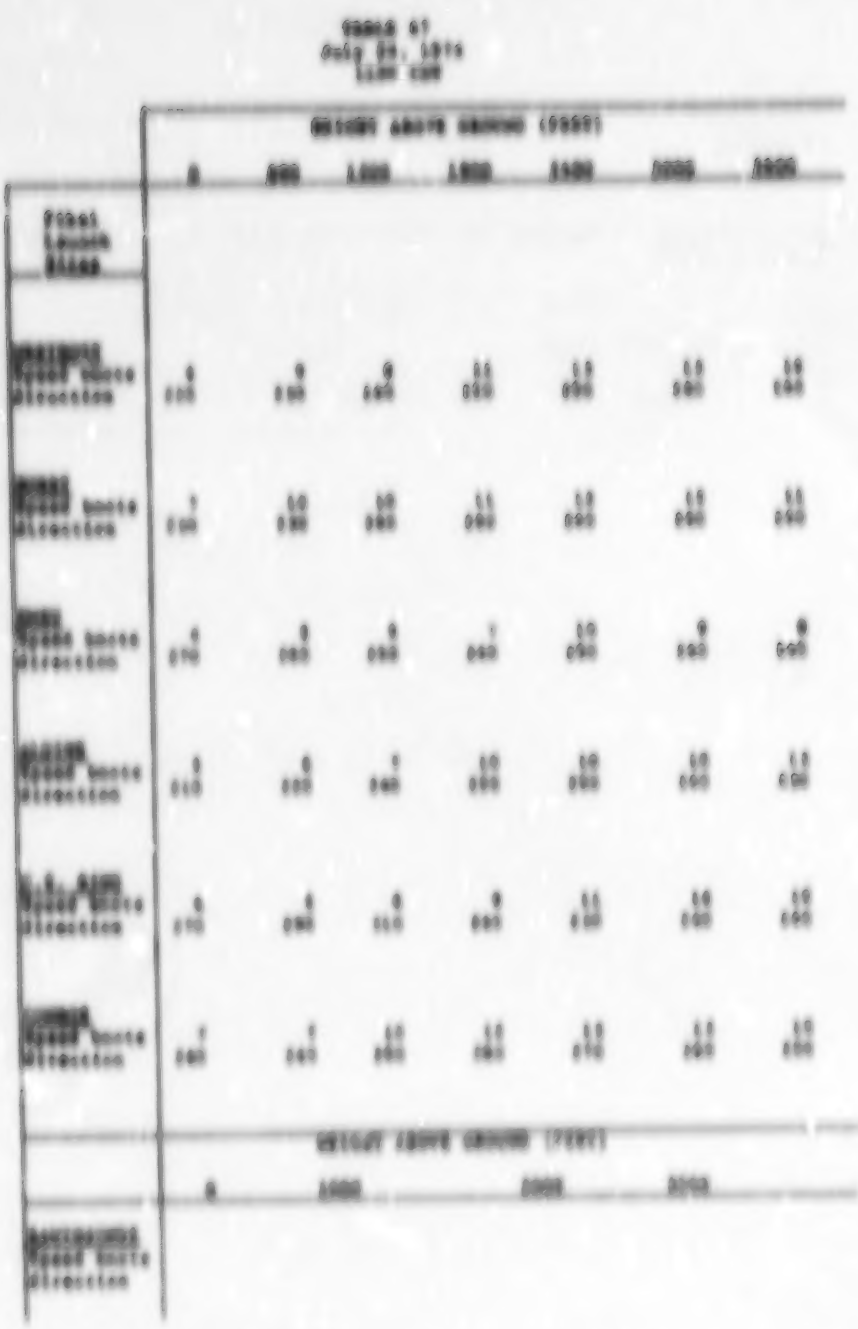
[illegible]

[illegible]

| [illegible] | [illegible] | | | | | | |
|---|---|---|---|---|---|---|---|
| | [illegible] | | | | | | |
| | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | | | | | |
| [illegible] | 1<br>000 | 13<br>050 | 10<br>080 | 10<br>050 | 10<br>050 | 10<br>050 | 10<br>010 |
| [illegible] | 1<br>030 | 14<br>040 | 11<br>040 | 09<br>040 | 03<br>040 | 10<br>040 | 12<br>041 |
| [illegible] | 0<br>000 | 11<br>000 | 10<br>047 | 09<br>040 | 10<br>040 | 17<br>040 | 10<br>040 |
| [illegible] | 0<br>0 | 0<br>0 | 10<br>050 | 10<br>050 | 12<br>050 | 10<br>040 | 10<br>010 |
| [illegible] | 1<br>030 | 0<br>040 | 09<br>041 | 12<br>050 | 01<br>040 | 10<br>040 | 11<br>050 |
| [illegible] | 0<br>000 | 10<br>000 | 11<br>040 | 03<br>040 | 01<br>040 | 10<br>040 | 10<br>040 |
| | [illegible] | | | | | | |
| | 0 | [illegible] | | [illegible] | | [illegible] | |
| [illegible] | 0<br>000 | 10<br>000 | | 01<br>040 | | 10<br>010 | |

[illegible]

| [illegible] | [illegible] | | | | | | |
|---|---|---|---|---|---|---|---|
| | [illegible] | | | | | | |
| [illegible] | [illegible] | | | | | | |
| [illegible] | [illegible] | | | | | | |
| [illegible]



## APPENDIX A

Conversion Factors for Physical Quantities into the International System of Units

Note that the E system for expressing power is used. That is, 3.5238 - 01 = $3.523 \times 10^{-1}$

| to convert from | to | multiply by |
|---|---|---|
| foot | meter | 3.048 000 E-01 |
| knot | meter/sec. | 5.144 444 E-01 |
| Fahrenheit (temperature) | Celsius | $t_C = (t_F - 32)/1.8$ |